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BACKSCAT Lidar Backscatter Simulation
User's Manual for Version 1.0

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BACKSCAT is a computer simulation of atmospheric backscatter from a laser radar (lidar) system. The simulation is based on atmospheric particulate models developed by the Geophysics Laboratory. Version 1.0 assumes a flat earth and neglects wind effects. The sensor may be positioned at any altitude, either exoatmospheric or endoatmospheric, and may be aimed in any viewing direction. The program, which can be executed interactively on IBM and compatible personal computers running under PC-DOS or MS-DOS, features a menu interface for ease of use. The choice of the FORTRAN '77 programming language allows BACKSCAT to be easily ported to other systems; the program is structured to minimize and isolate the routines which may require changes to accommodate other operating systems. This manual describes the operation and use of the BACKSCAT program.

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Contents

Illustrations

Tables

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BACKSCAT Lidar Backscatter Simulation
User's Manual for Version 1.0

1 INTRODUCTION

Backscatter from atmospheric aerosols can produce significant returns in monostatic laser radar (lidar) systems. The Air Force Geophysics Laboratory (AFGL) is developing lidar systems that will measure this backscatter. To aid in the design and use of such systems, SPARTA has developed a simulation program, BACKSCAT, that calculates the backscatter return for various lidar systems, viewing aspects, and atmospheric conditions. The preliminary version that is described in this report was designed to look at aerosol effects.

The BACKSCAT computer simulation code is designed to be easy to use while providing the operator with maximum flexibility. All simulation and configuration parameters can be changed interactively through an integrated menu interface. The simulation output is written in tabular form to a data file that can be read by standard plotting programs. A log file is also generated during the execution of the simulation that provides for verification of simulation inputs and traceability of results.

1.1 Organization of Report

This manual is a user's guide to the operation of the BACKSCAT lidar backscatter simulation code. Section 2 summarizes key features of the code itself. Section 3 describes the steps required to install the code on a computer system. Section 4 discusses the interactive execution of the code. Section 5 provides samples of the output generated by the simulation. Finally, Section 6 provides recommendations for future modifications.

Three appendices contain supplementary information about BACKSCAT. Appendix A summarizes the program modules that make up the code. Appendix B discusses the adaptations which may be necessary when installing the code on computers with different operating systems. Finally, Appendix C describes the format and syntax of the files used by BACKSCAT.

2 KEY FEATURES OF BACKSCAT

2.1 Computer System Portability

This version of BACKSCAT was developed on an IBM-compatible personal computer. The code was written and compiled using Microsoft™ Fortran version 4.01 of Fortran 77. Being written in Fortran 77, BACKSCAT should be able to run on virtually any host computer. Minor changes may be necessary when installing the code on other computer systems due to differences in operating systems, but every reasonable effort has been made to isolate these changes to a minimal number of subroutines. Appendix A contains a list of all of the programs that make up BACKSCAT and a brief description of what they do.

2.2 Summary of the Physics

BACKSCAT simulates the return from a monostatic lidar through a solution of the lidar equation (Cf. Klett[1]). The backscatter return observed by a lidar system operating at the wavelength λ is given by

$$P_R(\lambda,r) = P_T \tau c A_R [\beta_m(\lambda,r) + \beta_a(\lambda,r)] \frac{1}{2r^2} \exp\left(-2\int_0^r [\alpha_a(\lambda,r) + \alpha_m(\lambda,r)]dr\right)$$

where:

$P_R(\lambda,r)$ is the power received from range r,

τ is the pulse length,

c is the speed of light,

A_R is the collecting area of the receiver aperture,

P_T is the transmitted power,

$\beta_a(\lambda,r)$ is the aerosol backscatter coefficient at range r,

$\beta_m(\lambda,r)$ is the molecular backscatter coefficient at range r,

$\alpha_a(\lambda,r)$ is the aerosol attenuation coefficient at range r, and

$\alpha_m(\lambda,r)$ is the molecular attenuation coefficient at range r.

The lidar return can be normalized by dividing by the transmitter power to obtain the fractional power returned as a function of range. The lidar return can also be range compensated by multiplying by the square of the range to obtain a measure of the actual aerosol levels.

The simulation can be run with molecular backscatter and attenuation contributions included or excluded. One can also selectively include molecular backscattering and neglect molecular absorption and vice versa.

---

[1] Klett, J. D. (1981) Stable Analytical Inversion Solution for Processing Lidar Returns, Applied Optics 20:211.

BACKSCAT contains a database of attenuation and backscatter coefficients used in the AFGL aerosol models[2]. The user can also supply a specific set of aerosol and molecular attenuation and backscattering coefficients. The BACKSCAT simulation obtains the attenuation and backscatter coefficients by linear interpolation of an altitude index into a propagation profile table. The altitude at a particular range is obtained from the "flat earth" relationship

$$h(r) = h_o + r\sin(\phi)$$

where:

$h(r)$ is the altitude at range r,

h_o is the sensor altitude, and

ϕ is the sensor viewing elevation angle.

The area of the receiver aperture, A_R, is computed from the specified aperture and obscuration diameters, assuming a standard circular aperture with a single circular obscuration.

2 R.W. Fenn et al. (1985), "Optical Infrared Properties of the Atmosphere", Chapter 18 in *Handbook of Geophysics and the Space Environment*, A.S. Jursa (ed.), Air Force Geophysics Laboratory, Hanscom Air Force Base, Massachusetts, AFGL-TR-85-0315, ADA167000, and E.P. Shettle (1988) Private Communication.

3 INSTALLATION

3.1 Installation on IBM or Compatible Computers

BACKSCAT is designed to operate on an IBM or compatible personal computer with an 8087 math co-processor and operating with PC-DOS or MS-DOS. The code can be run on computers with dual floppy disk drives or a hard disk. The use of hard disk is recommended.

To install the code, insert the diskette containing the executable program into a $5\frac{1}{4}$ inch diskette drive and then type the command:

```
[d1:]INSTALL d1:  [d2:][directory]
```

and then press the ENTER or RETURN key. (For simplicity sake, we shall only make reference to the ENTER key in this report but its use is the same as the RETURN key.) In the above command, `d1:` is the diskette drive containing the programs, `d2:` is the destination drive, and `directory` is the directory or subdirectory into which the program is to be installed. (The components of the INSTALL command line shown in brackets are optional and the brackets are not typed when the command is entered). If a destination directory is not specified, the current default directory will be assumed. If a specific destination directory is desired, it must be created prior to installation. (If the program is to be customized, the source (.FOR) files must also be copied from the source distribution diskette using the PC-DOS or MS-DOS COPY command.)

If an error is made during the installation procedure, such as from neglecting to add the `d1:` after the command `INSTALL`, an error message will be displayed on the monitor. Correct the installation commands that were entered and press the ENTER command.

3.2 Installation on Non PC or MS-DOS Computers

Installation of the BACKSCAT program on a computer using another operating system is slightly more complex. The source and program data files (all files on the source distribution diskette) must first be transferred from the source program distribution diskette to the host computer system. The source files must then be compiled and linked on the host system to create the correct executable code. It may additionally be necessary to rename files and/or modify some subroutines to accommodate operating system differences, as described in Appendix B.

The DOS file ANSII.SYS file should be added to the AUTOEXEC.BAT file for the computer on which BACKSCAT will be run. This will enable the code to take full advantage of the menu operations of the program.

4 PROGRAM OPERATION

4.1 Beginning the Program

The BACKSCAT program may be executed under PC-DOS or MS-DOS by entering the program name (BACKSCAT) at the DOS system prompt and then press ENTER. The required commands for executing BACKSCAT on computers with different operating systems may differ and the user is urged to consult the appropriate operating system manual for specific instructions.

BACKSCAT first displays a title screen, as shown in Figure 1, with a prompt for a system configuration. The user must enter the name of an *existing* configuration. A configuration named DEFAULT is supplied with the program and must be entered the first time BACKSCAT is used. Additional configurations may be created by the user within the program as described below and subsequently used for program initialization. The program converts the configuration name to a file name and attempts to read the information in the file. If the program cannot locate the specified configuration file, a message will be displayed prompting the user to enter another configuration name. The user is cautioned not to change the conditions specified in the DEFAULT configuration file.

The configuration file name also contains names of files that describe the lidar system and atmospheric structure to be modeled. If either file cannot be located, the user is prompted for another name.

4.2 Menu Control System

BACKSCAT utilizes a series of master menus to define a set of simulation parameters. These parameters define the lidar system, atmospheric structure, and configuration conditions. These master menus, in turn, link to a series of submenus that permit the user to define the individual parameters.

Each master menu or submenu is divided into a status area and a dialog area separated by a row of asterisks. The status area displays the current set of conditions. The dialog area contains prompts to aid the user in changing any of the operating conditions.

4.3 Main Program Status

Once the desired configuration has been loaded, the program will display a Main Status Menu, as shown in Figure 2, showing the conditions of the specified configuration. The values shown in the figure and subsequent figures correspond to the default configuration.

The Main Status Menu displays the names of the files containing the information about the lidar system, the atmospheric model, the propagation profile, the molecular absorption profile, the simulation log, the simulation output, and the mode of propagation. The dialog area at the

```
BACKSCAT -- LIDAR Backscatter Program

SPARTA, Inc., Lexington, MA

Please enter name of desired configuration.
```

Figure 1. Opening Menu of BACKSCAT Displaying the Prompt for the Name of the Desired Configuration

bottom of the menu contains letters that one can use to change any of the above parameters. If one does not enter a given letter, the program will automatically scroll through each parameter. The monitor will display the current values for the given parameter and a prompt to enter the new information. Text entries can be entered in upper or lower case letters. The program will automatically convert the text to upper case. If one does not wish to change a given parameter, press the ENTER key.

4.4 Quitting Menus and Program Termination

The "Q -- Quit" option on any menu universally passes control out of that menu. From any menu other than the Main Status Menu, control reverts to the next higher menu. When the "Q -- Quit" option is selected from the Main Status Menu, the program terminates and returns control to the operating system. Menus that do not include a "Q -- Quit" option (generally used where the user must select a value from a discrete set of valid responses) will automatically

```
LIDAR System                                              DEFAULT
Atmospheric Model                                         DEFAULT
Propagation Profile                                          TEST
Molecular Absorption                                       (NONE)
Simulation Log                                            DEFAULT
Simulation Output                                         DEFAULT
MODE: Prop./Rayleigh                          ATMOS. MODEL / ON
*************************************************************************
L -- LIDAR System                     A -- Atmospheric Structure
P -- Propagation Profile              M -- Molecular Absorption
S -- Simulation                       C -- Configuration
Q -- Quit

Enter Selection, or Press ENTER Key for Default (Highlighted) Selection.
```

Figure 2. Main Status Menu Displaying the Conditions of the Specified Configuration

return control to the next higher menu when the selection is completed.

When the user chooses to quit any of the master menus, BACKSCAT first checks to see if any changes were made to the affected data set (lidar system, atmospheric structure, or configuration). If changes were made, the quit submenu is displayed and the user may choose "C -- Cancel" to cancel the changes, "K -- Keep" to keep the changes for the current session without saving to a file, or "S -- Save" to save the modified data set to a file. If the user chooses to save the modified data set, the current name for the data sets (lidar system, atmospheric structure, or configuration) is used, overwriting any existing data set with the same name.

```
     Name of System                                                     TEST

     Sensor Height (Kilometers)                                          0.0

     Viewing Azimuth (Degrees)                                           0.0

     Viewing Elevation (Degrees)                                          45
******************************************************************************

N -- Name of System           L -- Load System             T -- Transmitter
R -- Receiver                 S -- Signal Processor        H -- Sensor Height
A -- Azimuth                  E -- Elevation Angle         Q -- Quit

Enter Selection, or Press ENTER Key for Default (Highlighted) Selection.
```

Figure 3. The Master Lidar System Menu

4.5 Changing Lidar Systems

The parameters governing the lidar system may be changed by selecting the "L -- Lidar System" option from the Main Status Menu. This option will result in the display of the Master Lidar System Menu as shown in Figure 3. To change a given parameter, either type the letter corresponding to the parameter and press ENTER or press ENTER until the program scrolls to the desired parameter.

4.5.1 "N -- Name of System" Option

This option prompts the user for a new lidar system name. The current name will be displayed along with a prompt for the new name. Type in the new name, using eight characters or less, and press ENTER. If you do not wish to make a change, merely press ENTER. The name entered will be displayed on the Master Lidar System Menu.

4.5.2 "L -- Load" Option

This option converts the lidar system name to a file name. If the file exists, the program then loads the lidar system information contained in the file. If the file does not exist, the information relating to the current lidar system is retained and referenced by the new name.

4.5.3 "T -- Transmitter" Option

This option displays the Lidar Transmitter Submenu, as shown in Figure 4, displaying the current transmitter parameters. The parameters that can be changed are the lidar wavelength, in microns; the pulse energy, in joules; and the pulse duration, in microseconds. To change a transmitter parameter, type the letter of the parameter and press ENTER or press ENTER until the desired parameter is displayed in the dialog area. To return to the Master Lidar System Menu, type "Q -- Quit" and press ENTER.

```
Wavelength (Microns)                                              .55

Pulse Energy (Joules)                                             1.0

Pulse Duration (Microseconds)                                     1.0

******************************************************************************

  TRANSMITTER:                  W -- Wavelength                E -- Pulse Energy
D -- Pulse Duration             Q -- Quit

Enter Selection, or Press ENTER Key for Default (Highlighted) Selection.
```

Figure 4. The Lidar Transmitter Submenu

4.5.4 "R -- Receiver" Option

This option displays the Lidar Receiver Submenu, as shown in Figure 5, showing the current receiver parameters. The parameters that can be changed are the receiver aperture diameter, in centimeters, and the receiver obscuration diameter, in centimeters. To change one of the parameters, type the letter of the choice and press ENTER or press ENTER until the parameter appears in the dialog area. To return to the Master Lidar System Menu, type Q and press ENTER.

```
   Aperture Diameter (Centimeters)                                   100.0

   Obscuration Diameter (Centimeters)                                  0.0


*******************************************************************************

 RECEIVER:                                       A -- Aperture Diameter
O -- Obscuration Diameter                        Q -- Quit


Enter Selection, or Press ENTER Key for Default (Highlighted) Selection.
```

Figure 5. The Lidar Receiver Submenu

4.5.5 "S -- Signal Processor" Option

This option displays the Lidar Signal Processor Submenu, as shown in Figure 6, and the current signal processor parameters menu. The signal processor parameters are the nearest or minimum range that can be detected, in kilometers, and the farthest or maximum range, in kilometers. To change a parameter, enter the letter displayed and press ENTER or press ENTER

```
Nearest Range (Kilometers)                                          0.0

Farthest Range (Kilometers)                                         100.0

Range Resolution (Kilometers)                                       .5

******************************************************************************

  SIGNAL PROCESSOR:              N -- Nearest Range            F -- Farthest Range
R -- Range Resolution            Q -- Quit

Enter Selection, or Press ENTER Key for Default (Highlighted) Selection.
```

Figure 6. The Lidar Signal Processor Submenu

until the parameter appears in the dialog area. To return to the Main Lidar System Menu, type Q and press ENTER.

4.5.6 Sensor Location and Viewing Aspect

The user may select "H -- Sensor Height" to specify the altitude of the sensor above the ground. Similarly, the user may specify the viewing direction by selecting "A -- Azimuth Angle" or "E -- Elevation Angle" to specify the azimuth and elevation angles, respectively.

The altitude must be entered in kilometers, and both angles must be entered in degrees. The elevation angle is measured in degrees above (positive) or below (negative) the horizontal plane. The azimuth angle currently has no effect, but is included for use in future upgrades to the simulation.

4.5.7 "Q -- Quit" Option

This option exits the Master Lidar System Menu and returns control to the Main Status Menu. Type Q and press ENTER.

4.6 Atmospheric Model

The atmospheric structure specifications for the AFGL atmospheric model may be changed by selecting the "A -- Atmospheric Model" option from the Main Status Menu. This option displays the Master Atmospheric Model Menu, as shown in Figure 7.

```
    Name of Structure                                                DEFAULT

    Upper Atmosphere -- Aerosol Level                                 NORMAL

    Stratosphere -- Aerosol Extinction                            BACKGROUND
                 -- Aerosol Profile                               BACKGROUND

    Troposphere -- Humidity                                               70

    Boundary Layer -- Aerosol                                          RURAL
                   -- Humidity                                            70
                   -- Visibility                                          23

    Aerosol Distribution                                         FALL/WINTER
****************************************************************************

N -- Name of Structure      L -- Structure              B -- Boundary Layer
T -- Troposphere            S -- Stratosphere           U -- Upper Atmosphere
D -- Distribution           H -- Heights of Layers      Q -- Quit

Enter Selection, or Press ENTER Key for Default (Highlighted) Selection.
```

Figure 7. Master Atmospheric Model Menu

In the AFGL atmospheric models, the atmosphere is divided into four layers. From the ground upward, these layers are the boundary layer, the troposphere, the stratosphere, and the upper atmosphere. The heights of each of the layer boundaries are currently preset but can be set by the user if an appropriate data base is supplied.

The data base that is required is a table of extinction coefficients for a wavelength of 0.55 μm as a function of altitude for one of the AFGL reference aerosol models. This data base contains the information on how to scale the aerosol abundances as a function of altitude. The default values that are provided with BACKSCAT are contained in a file called STANDARD.SCL. The data in the file are read in with the FORTRAN format (F6.1,9E8.2). Each record of the file contains the altitude, in km, and the extinction coefficients for different conditions. (The precise columnar format of the data file are based on Table 18-10a. from Fenn et al.[2].)

4.6.1 "N -- Name of Structure" Option

This option prompts the user for a new atmospheric structure name. To enter a new name, type a name of eight characters or less, and press ENTER. The name entered becomes the name of the current atmospheric structure.

4.6.2 "L -- Load" Option

This option converts the atmospheric structure name to a file name. If the file exists, the program then loads the information about the atmospheric structure contained in the file. If the file does not exist, the information about the currently displayed atmospheric structure is retained and referenced by the new name.

4.6.3 "B -- Boundary Layer" Option

This option is used to describe the aerosol conditions in the planetary boundary layer. The conditions under user control are the type of aerosol, the surface value of the relative humidity, and the surface value of visibility. This option displays the boundary layer submenu. To select this option, type B and press ENTER.

4.6.3.1 "A -- Aerosol" Option

This option allows the user to describe the type of aerosols in the boundary layer. The user can select "R -- Rural" for rural aerosols, "U -- Urban" for urban aerosols, "M -- Maritime" for maritime aerosols, "O -- Oceanic" for oceanic aerosols, "T -- Tropospheric" for tropospheric aerosols, or "F -- Fog" for fog conditions. Type in the appropriate letter and press ENTER.

If the user selects fog conditions, the fog submenu is displayed. The user can then select "A -- Advective" for advective fog or "R -- Radiative" for radiative fog. Type A or R and then press ENTER. Upon completion of the selection, control returns to the boundary layer aerosol submenu.

4.6.3.2 "H -- Humidity" Option

This selection allows the user to specify the relative humidity at the surface of the boundary layer. Type in the desired value, in percent (%), and press ENTER.

4.6.3.3 "V -- Visibility" Option

This selection prompts the user for the visibility at the surface of the boundary layer, which is then used to calculate the extinction coefficient at the surface. To enter the visibility, enter a positive value, in km. One can also assume that the extinction coefficient in the boundary layer is uniform throughout the boundary layer. To invoke this option, enter a negative value, in km^{-1}. Press ENTER after either value has been typed in.

4.6.3.4 "Q -- Quit" Option

This selection returns control to the Master Atmospheric Model Menu. Type Q and press ENTER.

4.6.4 "T -- Tropospheric Humidity" Option

This option prompts the user for the relative humidity of the troposphere. Type in the desired value, in percent (%), and press ENTER.

4.6.5 "S -- Stratosphere" Option

The Stratosphere Option is used to describe the aerosol conditions in the stratosphere. The conditions that must be specified are the type and profile of the stratospheric aerosols. To select this option, type S and press ENTER.

4.6.5.1 "E -- Extinction" Option

This selection displays the choices for the stratospheric extinction. The user can choose "B -- Background" for background extinction conditions, "F -- Fresh Volcanic" for fresh volcanic extinction conditions, or "A -- Aged Volcanic" for aged volcanic extinction conditions. Type B, F or A and press ENTER. Control will then return to the stratospheric submenu.

4.6.5.2 "P -- Profile" Option

This selection displays the choices for the stratospheric profile. The user can choose "B -- Background" for a background stratospheric aerosol profile, "M -- Moderate Volcanic" for a moderate volcanic aerosol profile, "H -- High Volcanic" for a high volcanic aerosol profile, or "E -- Extreme Volcanic" for an extreme volcanic aerosol profile. Type in the letter of the desired choice and press ENTER. Control returns to the stratospheric menu after a selection is made.

4.6.5.3 "Q -- Quit" Option

This selection returns control to the Master Atmospheric Model Menu. Type Q and press ENTER.

4.6.6 "U -- Upper Atmosphere" Option

This selection displays the options for the upper atmosphere aerosols. The user can choose "N -- Normal" for normal upper atmospheric aerosol conditions or "E -- Extreme" for extreme meteoric aerosol conditions. Type N or E and then press ENTER. After a selection is made, control returns to the Master Atmospheric Model Menu.

4.6.7 "D -- Distribution" Option

This selection displays the choices for the seasonal aerosol distributions. The user can select from a Fall/Winter aerosol profile or Spring/Summer aerosol profile. Type F or S and then press ENTER. Control then returns to the Master Atmospheric Model Menu.

4.6.8 "H -- Heights of Layers" Option

This option displays the Aerosol Layer Height Submenu, as shown in Figure 8, and allows the user to change the boundary heights between different types of aerosols. The user may select "B --Boundary Layer" to set the upper limit of the boundary layer, "T -- Troposphere" to set the upper limit of the troposphere, "S -- Stratosphere" to set the upper limit of the stratosphere "U -- Upper Atmosphere" to set the upper limit of the assumed upper atmosphere, or "Q -- Quit" to return control to the Master Atmospheric Model Menu. Type in the letter corresponding to one's choice and press ENTER. The program will prompt the user to enter a new boundary layer height in kilometers. The lower limit of the boundary layer, of course, is zero. The lower limit of the other layers is the upper limit of the next lower layer.

The values for layer heights that are supplied in the default configuration correspond to those in the AFGL model atmospheres and correspond to the scaling factors discussed in Section 4.6. If these heights are to be changed, the user must supply a new set of aerosol scale factors which are contain the new set of layer heights. Or, the code must be modified to include a procedure for interpolating the scale factors for the user supplied layer heights.

4.6.9 "Q -- Quit" Option

This option exits the Master Atmospheric Model Menu and returns control to the Main Status Menu. Type Q and then press ENTER.

```
Height of Boundary Layer (Kilometers)                              2.0

Height at Top of Troposphere (Kilometers)                          9.0

Height at Top of Stratosphere (Kilometers)                        29.0

Height at Limit of Atmosphere (Kilometers)                       100.0
************************************************************************

 LAYER HEIGHTS:              B -- Boundary Layer        T -- Troposphere
S -- Stratosphere            U -- Upper Atmosphere      Q -- Quit

Enter Selection, or Press ENTER Key for Default (Highlighted) Selection.
```

Figure 8. The Aerosol Layer Height Submenu

4.7 Propagation Profile Name

If "P -- Propagation Profile" is selected from the Main Status Menu, the user is prompted for a new propagation profile name. Type in a name of eight characters or less and press ENTER.

When the simulation is executed from the Main Status Menu, as described below, the propagation profile name is converted to a file name. If the propagation mode is set for propagation profile, the corresponding file is *read* to obtain the propagation data and the atmospheric model is ignored. If the propagation mode is set for atmospheric model, a propagation profile is generated by the atmospheric model for the current atmospheric structure and *written* to the corresponding file, overwriting any existing file of the same name.

When the propagation mode is selected to the propagation, so that the simulation will read a propagation profile from a file, the file must be written in standard tabular form. The columns of the propagation profile must be: (1) altitude (kilometers), (2) aerosol extinction coefficient (inverse kilometers), (3) aerosol absorption coefficient (inverse kilometers), (4) aerosol scatter coefficient (inverse kilometers), (5) aerosol backscatter coefficient (inverse meter-steradians), (6) molecular extinction coefficient (inverse kilometers), and (7) molecular backscatter coefficient (inverse meter-steradians).

The term "standard tabular form" means that each row of data correspond to a separate altitude. The data are read in "free format" form. Altitudes must appear in increasing order. Although there is no limit to the number of altitudes that may appear in a data file, the current version of BACKSCAT will only read the first one hundred lines of data.

4.8 Molecular Absorption

The "M - Molecular Absorption" option allows the user to specify a molecular absorption profile for use by the lidar equation. If the user does not wish to include molecular absorption, type in (NONE) or NONE. If the user wishes to include molecular absorption, enter in the name (without any file extensions) of the file containing the absorption data.

The file containing the molecular absorption must contain two columns of data; the first column is the altitude in kilometers and the second column is the absorption coefficient in inverse kilometers. The data must be arranged such that the altitudes are in increasing order.

4.9 Simulation

The simulation option may be entered by selecting "S -- Simulation" from the Main Status Menu. The user will then be given the option to select "L -- Log Name" to change the name of the simulation log, "O -- Output" to change the name of the simulation output (data) file, "R -- Run Simulation" to execute the backscatter simulation, or "Q -- Quit" to return to the main menu. Type the appropriate letter and press ENTER.

4.10 Changing the System Configuration

Selecting "C -- Configuration" from the Main Status Menu will display the Master Configuration Menu as shown in Figure 9. Each user will normally set up a configuration tailored to the host system, applications, and configuration preferences. This configuration should be saved for use during subsequent sessions, so that it will not be necessary to reset the configuration from the default each time that the program is used. The features that make up a given configuration are described below.

4.10.1 "N -- Name" Option

This option prompts the user for a new configuration name. Type in a name of eight characters or less and press ENTER. The name entered by the user immediately becomes the name of the current configuration.

```
Name of Configuration                                          DEFAULT

Propagation Model                                    ATMOSPHERIC MODEL

Rayleigh Scattering Mode                                            ON

****************************************************************************

N -- Name                 L -- Load                   D -- Display
R -- Run Set              P -- Propagation Mode       S -- Scattering Mode
Q -- Quit

Enter Selection, or Press ENTER Key for Default (Highlighted) Selection.
```

Figure 9. Master Configuration Menu

4.10.2 "L -- Load" Option

This option converts the configuration name to a file name. If the file exists, the program then loads the configuration information contained in the file. If the file does not exist, the current configuration information is retained and referenced by the new name.

4.10.3 "D -- Display" Option

This option displays the Terminal Display Submenu, which is shown in Figure 10. The terminal display parameters that are set from this submenu enable the program to adapt the menu control system to the characteristics of the user's terminal.

Changes to the display characteristics that are selected from this submenu will take effect upon quitting the Master Configuration Menu unless the "C -- Cancel" option is selected from the quit submenu. This behavior allows the user to correct a mistake or cancel a series of inadvertent changes without the screen becoming jumbled.

```
Terminal Type                                                        ANSI

Screen Length                                                          25

Screen Width                                                           80

Status Area Margins                                                     5

Atmospheric Display                                                NORMAL
*************************************************************************

T -- Terminal        C -- Control Char    A -- Atmos Displ    Q -- Quit
  SCREEN SIZE:       L -- Length          W -- Width          M -- Margins

Enter Selection, or Press ENTER Key for Default (Highlighted) Selection.
```

Figure 10. Terminal Display Submenu

4.10.3.1 "T -- Terminal" Option

This selection displays the choices for terminal type. The terminal selection consists of only two options, ANSI or GENERIC. Users of IBM or IBM-compatible computers (such as the Zenith 248) or users with terminals conforming to ANSI standard (VT-100, etc.) should select the "A -- ANSI" option and select the ANSI control character sequences from the Control Character submenu (see Subsection 4.10.3.2.) This use of this option requires the use of the PC-DOS or MS-DOS ANSI.SYS display driver which must be called from the AUTOEXEC.BAT file during computer system "boot-up." For systems that do not conform to the ANSI standard for terminal control, the "G -- Generic" option must be selected.

Selecting the ANSI terminal option allows the program to use ANSI terminal control ("escape") strings for screen control. When the ANSI option is in effect, the following features are used in the menu displays:

- Scrolling is eliminated by removing irrelevant information from the screen and positioning new information where it is desired.

- Default menu selections are highlighted by reverse video. (The generic display driver writes a separate line to indicate the default selection.)
- Program messages signifying normal execution are displayed in high intensity text.
- Error messages are displayed in blinking high intensity text.

These enhancements provide a more intuitive and less distracting interface for most users, but may not be available on all hardware. The terminal must support the ANSI protocol, and the computer must be capable of transmitting two control characters described below to the terminal. All of the menus and submenus displayed in this users guide were generated on an ANSI terminal.

4.10.3.2 "C -- Control Char" Option

The Control Character Submenu, which is shown in Figure 11, is displayed by selecting the "C - Control Char" option from the Terminal Display submenu. This submenu is used to define the parameters used to determine the "escape" control character and the "set graphics rendition" character, in BACKSCAT parlance, which is used to activate and deactivate reverse video, high intensity, blinking, and other display attributes.

Since many computer systems support either of two standard character sets (the 8-bit ANSI set and IBM's EBCDIC set), the control characters from these character sets are built into the program and can be set by selecting the "A -- ANSI" and "I -- IBM" options, respectively. For system configurations not conforming to the either of these standards, the "E -- ESCAPE" and "G -- Graphics" options may be used to set strings to be substituted for the escape and set graphics rendition characters respectively. Up to five characters may be entered by their decimal positions in the collating sequence of the host computer for each of these strings. This entry format makes the entire character set of the host computer available.

4.10.3.3 "A -- Atmos Displ" Option

This option displays the choices regarding how the information about the atmospheric aerosols will be displayed on the screen. If "N -- Normal" is selected, the information about the highest aerosol layers in the atmosphere will appear near the top of the screen and that about the lowest near the bottom (see Figure 7.) If "I -- Inverted" is selected, this sequence will be reversed. Type N or I and then press ENTER.

```
ESCAPE Sequence                                                   27

ATTRIB Sequence                                                  109

****************************************************************************

  ANSI CONTROL:              E -- Escape Sequence        G -- Graphics Sequence
A -- ASCII Standard Set      I -- IBM (EBCDIC) Set       Q -- Quit

Enter Selection, or Press ENTER Key for Default (Highlighted) Selection.
```

Figure 11. The Control Character Submenu

4.10.3.4 Screen Size Options

The "L -- Length" and "W -- Width" options respectively set the number of lines (vertically) and number of characters (horizontally) of the screen. The "M -- Margins" option sets the width of the left and right margins, in characters, in the status display area. Type the appropriate response and press ENTER. On systems that reserve one or more lines at the top or bottom of the screen for status display, the screen length should be set to the number of *available* lines.

4.10.3.5 "Q -- Quit" Option

This selection returns control to the Master Configuration Menu. Type Q then press ENTER.

4.10.4 "R -- Run Set" Option

This option displays the current run set, as shown in the Run Set Submenu in Figure 12, consisting of the lidar system name, the atmosphere name, the propagation profile name, the molecular absorption profile name, the simulation log name, and the simulation output name. The run set submenu allows each of these to be changed. This submenu is included primarily as a convenience for changing the default run set elements to be saved in a configuration file. Each element of the run set can also be selected from another menu outside the control of the Master Configuration Menu.

```
     LIDAR System                                                 DEFAULT
     Atmospheric Model                                            DEFAULT
     Propagation Profile                                             TEST
     Molecular Absorption                                          (NONE)
     Simulation Log                                               DEFAULT
     Simulation Output                                            DEFAULT
*****************************************************************************

  RUN SET:                                     S -- LIDAR System
A -- Atmospheric Model                         P -- Propagation Profile
M -- Molecular Absorption                      L -- Simulation Log
O -- Simulation Output                         Q -- Quit

Enter Selection, or Press ENTER Key for Default (Highlighted) Selection.
```

Figure 12. The Run Set Submenu

4.10.5 "P -- Propagation Mode" Option

This selection displays the options that allow the user to select either of two modes by which the backscatter can be computed. If the "A -- Atmospheric Model" option is selected, the simulation will compute the atmospheric propagation coefficients from the AFGL atmospheric model and *write* them to the file associated with the propagation profile name. If the "P -- Propagation Profile" option is selected, the simulation will *read* the propagation coefficients from the file associated with the propagation profile name. (Section 4.6 describes the format requirements of a user-supplied propagation profile.)

4.10.6 "S -- Scattering Mode" Option

This selection displays the options regarding the use of Rayleigh scattering. The user may select "Y -- Yes" to include Rayleigh scattering or "N -- No" to neglect Rayleigh scattering. The status of the scattering mode is indicated as "ON" if Rayleigh scattering is included or "OFF" if it is not.

4.10.7 "Q -- Quit" Option

This option exits the Master Configuration Menu and returns control to the Main Status Menu. To select this option, type Q and press ENTER.

4.11 Execution in Batch Mode

The BACKSCAT program may be executed in batch mode by redirecting standard input to a script file using the redirection capabilities of the operating system. (Under PC-DOS and MS-DOS, the < and > characters are used to redirect standard input and standard output respectively.) A script file is a input text file containing the consecutive entries that would be supplied interactively through the menu system; it can be prepared using an ASCII text editor. All functions supported by the menu system can be performed through appropriate entries in the script file. The script file shown in Figure 13 loads a configuration, renames the output, executes the simulation, and exits the program; the parenthetical comments are optional. All text in a script file is automatically converted to UPPER CASE in the same manner as interactive input.

For batch mode execution, standard output should also be redirected to a "null" or "phantom" file or device that serves to suppress output (for example, the PC-DOS or MS-DOS device "NUL") if possible, as standard output is used only to display the screens and messages of the menu control system. In case of difficulty, this information can instead be redirected to a file and subsequently matched with the script file as a diagnostic measure.

```
MYCONFIG     (initial configuration name)
S            (select simulation from main menu)
O            (select output name from simulation menu)
MYOUTPUT     (new output name)
R            (select run simulation)
Q            (quit simulation menu)
Q            (quit program)
```

Figure 13. A Sample Script File for Batch Mode Execution of BACKSCAT

5 SAMPLE OUTPUT

The simulation, whether executed interactively or in batch mode, always generates an output file and a log file. The lidar output file contains the backscatter data in standard tabular form for input into any standard plotting program; many such programs are available commercially. The columns of the output file are: (1) range (kilometers), (2) altitude (kilometers), (3) cumulative attenuation factor (''optical depth''), (4) lidar backscatter (Watts), (5) normalized backscatter, (6) range-compensated backscatter (Watt-square meters), and (7) normalized range-compensated backscatter (square meters).

The log file provides a trace of the simulation execution that can be used to validate results. Log files are self-documenting, and their contents varies depending upon the simulation mode options that are in effect for the particular execution. A sample log file is shown in Figure 14 with only a partial print out of the lidar backscatter return data.

When the propagation mode is selected to the atmospheric model, the simulation also generates a propagation profile file. The propagation profile file is also in standard tabular form for input into any standard plotting program; it can additionally be input into he simulation on subsequent executions by selecting the propagation mode to the propagation profile. The columns of the propagation profile are: (1) altitude (kilometers), (2) aerosol extinction coefficient (inverse kilometers), (3) aerosol scattering coefficient (inverse kilometers), (4) aerosol absorption coefficient (inverse kilometers), (5) aerosol backscatter coefficient (inverse meters-steradians), (6) molecular extinction coefficient (inverse kilcmeters), and (7) molecular backscatter coefficient (inverse meters-steradians).

Figures 15-17 show the results from a sample run. Figure 15 shows the propagation profile created by the specific choice of atmospheric properties and aerosols. The scattering coefficient is hidden behind the total extinction curve since the absorption at this wavelength is relatively small. The backscatter coefficient is also shown on the same graph with the same scale but different units. Figure 16 and 17 show the lidar backscatter return with the $1/R^2$ dependence included and removed, respectively.

```
***************************************
*                                     *
*     LIDAR Backscatter Simulation    *
*            (Version 1.1)            *
*                                     *
*            Simulation Log           *
*                                     *
***************************************

                ***** LIDAR SYSTEM *****

Transmitter Parameters:
          Wavelength (um)                          .55
          Pulse Energy (J)                         1.0
          Pulse Duration (us)                      1.0

Receiver Parameters:
          Aperture Diameter (cm)                   100.0
          Obscuration Diameter (cm)                0.0

Signal Processor Parameters:
          Nearest (Minimum) Range (km)             0.0
          Farthest (Maximum) Range (km)            100.0
          Range Resolution (Kilometers)            .5

Viewing Aspect:
          Sensor Height (km)                       0.0
          Viewing Azimuth Angle (Deg)              0.0
          Viewing Elevation Angle (Deg)            45.0

              ***** ATMOSPHERIC MODEL *****

Boundary Layer:
          Aerosol                                  RURAL
          Visibility (km)                          23
          Relative Humidity (Percent)              70.0

Troposphere:
          Relative Humidity (Percent)              70.0

Stratosphere:
          Aerosol Extinction                   BACKGROUND
          Aerosol Profile                      BACKGROUND

Upper Atmosphere:
          Aerosol Level                            NORMAL

Aerosol Distribution:                      FALL/WINTER

Layer Heights:
          Boundary Layer (km)                        2.0
          Troposphere (km)                         9.0
          Stratosphere (km)                        29.0
          Top of Atmosphere (km)                   100.0

    Propagation profile written to file TEST.PFL
```

Figure 14. Sample Log File Output

***** PROPAGATION PROFILE *****

Height (km)	Extinct (1/km)	Scatter (1/km)	Absorp (1/km)	B'scatter (1/m-sr)	Mol Ext (1/km)	Mol B'scat (1/m-sr)
.00	1.580E-01	1.494E-01	8.491E-03	3.466E-06	1.160E-02	1.385E-06
1.00	9.910E-02	9.373E-02	5.325E-03	2.174E-06	1.060E-02	1.265E-06
1.50	7.920E-02	7.491E-02	4.256E-03	1.737E-06	1.000E-02	1.194E-06
2.00	6.210E-02	5.874E-02	3.337E-03	1.362E-06	9.550E-03	1.140E-06
3.00	2.720E-02	2.621E-02	9.931E-04	5.918E-07	8.620E-03	1.029E-06
4.00	1.200E-02	1.156E-02	4.381E-04	2.611E-07	7.770E-03	9.275E-07
5.00	4.850E-03	4.673E-03	1.771E-04	1.055E-07	6.990E-03	8.344E-07
6.00	3.540E-03	3.411E-03	1.292E-04	7.702E-08	6.260E-03	7.472E-07
7.00	2.300E-03	2.216E-03	8.397E-05	5.004E-08	5.600E-03	6.684E-07
8.00	1.410E-03	1.359E-03	5.148E-05	3.068E-08	4.990E-03	5.956E-07
9.00	9.800E-04	9.442E-04	3.578E-05	2.132E-08	4.430E-03	5.288E-07
10.00	7.870E-04	7.870E-04	4.658E-11	1.124E-08	3.920E-03	4.679E-07
11.00	7.140E-04	7.140E-04	4.226E-11	1.020E-08	3.460E-03	4.130E-07
12.00	6.630E-04	6.630E-04	3.924E-11	9.468E-09	2.960E-03	3.533E-07
13.00	6.220E-04	6.220E-04	3.682E-11	8.882E-09	2.530E-03	3.020E-07
14.00	6.450E-04	6.450E-04	3.818E-11	9.211E-09	2.160E-03	2.578E-07
15.00	6.430E-04	6.430E-04	3.806E-11	9.182E-09	1.850E-03	2.208E-07
16.00	6.410E-04	6.410E-04	3.794E-11	9.153E-09	1.580E-03	1.886E-07
17.00	6.010E-04	6.010E-04	3.557E-11	8.582E-09	1.350E-03	1.611E-07
18.00	5.630E-04	5.630E-04	3.332E-11	8.040E-09	1.150E-03	1.373E-07
19.00	4.920E-04	4.920E-04	2.912E-11	7.026E-09	9.870E-04	1.178E-07
20.00	4.230E-04	4.230E-04	2.504E-11	6.040E-09	8.440E-04	1.007E-07
21.00	3.520E-04	3.520E-04	2.084E-11	5.027E-09	7.180E-04	8.570E-08
22.00	2.960E-04	2.960E-04	1.752E-11	4.227E-09	6.120E-04	7.305E-08
23.00	2.420E-04	2.420E-04	1.432E-11	3.456E-09	5.220E-04	6.231E-08
24.00	1.900E-04	1.900E-04	1.125E-11	2.713E-09	4.450E-04	5.312E-08
25.00	1.500E-04	1.500E-04	8.879E-12	2.142E-09	3.800E-04	4.536E-08
26.00	1.150E-04	1.150E-04	6.807E-12	1.642E-09	3.250E-04	3.879E-08
27.00	8.950E-05	8.950E-05	5.298E-12	1.278E-09	2.780E-04	3.318E-08
28.00	6.700E-05	6.700E-05	3.966E-12	9.568E-10	2.380E-04	2.841E-08
29.00	5.200E-05	5.200E-05	3.078E-12	7.426E-10	2.040E-04	2.435E-08
30.00	3.320E-05	3.320E-05	1.965E-12	4.741E-10	1.750E-04	2.089E-08
35.00	1.650E-05	1.650E-05	9.767E-13	2.356E-10	8.030E-05	9.585E-09
40.00	8.000E-06	8.000E-06	4.735E-13	1.142E-10	3.790E-05	4.524E-09
45.00	4.020E-06	4.020E-06	2.379E-13	5.741E-11	1.870E-05	2.232E-09
50.00	2.100E-06	2.100E-06	1.243E-13	2.999E-11	9.740E-06	1.163E-09
55.00	1.090E-06	1.090E-06	6.452E-14	1.557E-11	5.200E-06	6.207E-10
60.00	5.780E-07	5.780E-07	3.421E-14	8.254E-12	2.720E-06	3.247E-10
65.00	3.050E-07	3.050E-07	1.805E-14	4.355E-12	1.480E-06	1.767E-10
70.00	1.600E-07	1.600E-07	9.471E-15	2.285E-12	8.050E-07	9.609E-11
75.00	6.950E-08	6.950E-08	4.114E-15	9.925E-13	3.300E-07	3.939E-11
80.00	2.900E-08	2.900E-08	1.717E-15	4.141E-13	1.350E-07	1.611E-11
85.00	1.200E-08	1.200E-08	7.103E-16	1.714E-13	5.650E-08	6.744E-12
90.00	5.100E-09	5.100E-09	3.019E-16	7.283E-14	2.400E-08	2.865E-12
95.00	2.150E-09	2.150E-09	1.273E-16	3.070E-14	1.000E-08	1.194E-12
100.00	9.300E-10	9.300E-10	5.505E-17	1.328E-14	4.200E-09	5.013E-13

Molecular scattering model is ON.

No absorption from molecular resonances.

Simulation output written to file TEST.DAT

Figure 14. Sample Log File Output (cont'd)

***** LIDAR BACKSCATTER *****

Range (Km)	Height (Km)	Optical Depth (-)	Lidar Return (W)	Normalized Return (-)	Rng. Ind. Lidar (W-sq m)	Normalized Return (sq m)
5.000E-01	3.536E-01	7.951E-02	1.748E-03	1.748E-09	4.369E+02	4.369E-04
1.000E+00	7.071E-01	1.484E-01	3.370E-04	3.370E-10	3.370E+02	3.370E-04
1.500E+00	1.061E+00	2.070E-01	1.168E-04	1.168E-10	2.628E+02	2.628E-04
2.000E+00	1.414E+00	2.570E-01	5.312E-05	5.312E-11	2.125E+02	2.125E-04
2.500E+00	1.768E+00	3.001E-01	2.792E-05	2.792E-11	1.745E+02	1.745E-04
3.000E+00	2.121E+00	3.369E-01	1.597E-05	1.597E-11	1.437E+02	1.437E-04
3.500E+00	2.475E+00	3.674E-01	9.603E-06	9.603E-12	1.176E+02	1.176E-04
4.000E+00	2.828E+00	3.916E-01	5.958E-06	5.958E-12	9.533E+01	9.533E-05
4.500E+00	3.182E+00	4.103E-01	3.946E-06	3.946E-12	7.991E+01	7.991E-05
5.000E+00	3.536E+00	4.253E-01	2.794E-06	2.794E-12	6.986E+01	6.986E-05
5.500E+00	3.889E+00	4.375E-01	2.006E-06	2.006E-12	6.068E+01	6.068E-05
6.000E+00	4.243E+00	4.473E-01	1.508E-06	1.508E-12	5.429E+01	5.429E-05
6.500E+00	4.596E+00	4.556E-01	1.165E-06	1.165E-12	4.924E+01	4.924E-05
7.000E+00	4.950E+00	4.624E-01	9.075E-07	9.075E-13	4.447E+01	4.447E-05
7.500E+00	5.303E+00	4.683E-01	7.423E-07	7.423E-13	4.176E+01	4.176E-05
8.000E+00	5.657E+00	4.737E-01	6.162E-07	6.162E-13	3.944E+01	3.944E-05
8.500E+00	6.010E+00	4.788E-01	5.148E-07	5.148E-13	3.720E+01	3.720E-05
9.000E+00	6.364E+00	4.835E-01	4.342E-07	4.342E-13	3.517E+01	3.517E-05
9.500E+00	6.718E+00	4.879E-01	3.679E-07	3.679E-13	3.321E+01	3.321E-05
1.000E+01	7.071E+00	4.919E-01	3.134E-07	3.134E-13	3.134E+01	3.134E-05
1.050E+01	7.425E+00	4.957E-01	2.692E-07	2.692E-13	2.968E+01	2.968E-05
1.100E+01	7.778E+00	4.992E-01	2.319E-07	2.319E-13	2.806E+01	2.806E-05
1.150E+01	8.132E+00	5.024E-01	2.008E-07	2.008E-13	2.656E+01	2.656E-05
1.200E+01	8.485E+00	5.055E-01	1.753E-07	1.753E-13	2.525E+01	2.525E-05
1.250E+01	8.839E+00	5.084E-01	1.533E-07	1.533E-13	2.395E+01	2.395E-05
1.300E+01	9.192E+00	5.111E-01	1.345E-07	1.345E-13	2.273E+01	2.273E-05
1.350E+01	9.546E+00	5.136E-01	1.182E-07	1.182E-13	2.155E+01	2.155E-05
1.400E+01	9.899E+00	5.161E-01	1.040E-07	1.040E-13	2.039E+01	2.039E-05
1.450E+01	1.025E+01	5.184E-01	9.232E-08	9.232E-14	1.941E+01	1.941E-05
1.500E+01	1.061E+01	5.207E-01	8.223E-08	8.223E-14	1.850E+01	1.850E-05
1.550E+01	1.096E+01	5.228E-01	7.327E-08	7.327E-14	1.760E+01	1.760E-05
1.600E+01	1.131E+01	5.249E-01	6.507E-08	6.507E-14	1.666E+01	1.666E-05
1.650E+01	1.167E+01	5.268E-01	5.773E-08	5.773E-14	1.572E+01	1.5[illegible]2E-05
1.700E+01	1.202E+01	5.287E-01	5.118E-08	5.118E-14	1.479E+01	1.479E-05
1.750E+01	1.237E+01	5.304E-01	4.569E-08	4.569E-14	1.399E+01	1.399E-05
1.800E+01	1.273E+01	5.321E-01	4.074E-08	4.074E-14	1.320E+01	1.320E-05
1.850E+01	1.308E+01	5.337E-01	3.635E-08	3.635E-14	1.244E+01	1.244E-05
1.900E+01	1.344E+01	5.352E-01	3.263E-08	3.263E-14	1.178E+01	1.178E-05
1.950E+01	1.379E+01	5.367E-01	2.924E-08	2.924E-14	1.112E+01	1.112E-05
2.000E+01	1.414E+01	5.381E-01	2.626E-08	2.626E-14	1.050E+01	1.050E-05
2.050E+01	1.450E+01	5.395E-01	2.368E-08	2.368E-14	9.953E+00	9.953E-06
2.100E+01	1.485E+01	5.408E-01	2.132E-08	2.132E-14	9.404E+00	9.404E-06
2.150E+01	1.520E+01	5.420E-01	1.925E-08	1.925E-14	8.898E+00	8.898E-06
2.200E+01	1.556E+01	5.432E-01	1.740E-08	1.740E-14	8.424E+00	8.424E-06
2.250E+01	1.591E+01	5.444E-01	1.571E-08	1.571E-14	7.952E+00	7.952E-06
2.300E+01	1.626E+01	5.455E-01	1.423E-08	1.423E-14	7.528E+00	7.528E-06
2.350E+01	1.662E+01	5.465E-01	1.290E-08	1.290E-14	7.121E+00	7.121E-06
2.400E+01	1.697E+01	5.475E-01	1.166E-08	1.166E-14	6.717E+00	6.717E-06
2.450E+01	1.732E+01	5.485E-01	1.060E-08	1.060E-14	6.360E+00	6.360E-06
2.500E+01	1.768E+01	5.494E-01	9.616E-09	9.616E-15	6.010E+00	6.010E-06
⋮	⋮	⋮	⋮	⋮	⋮	⋮

Figure 14. Sample Log File Output (cont'd)

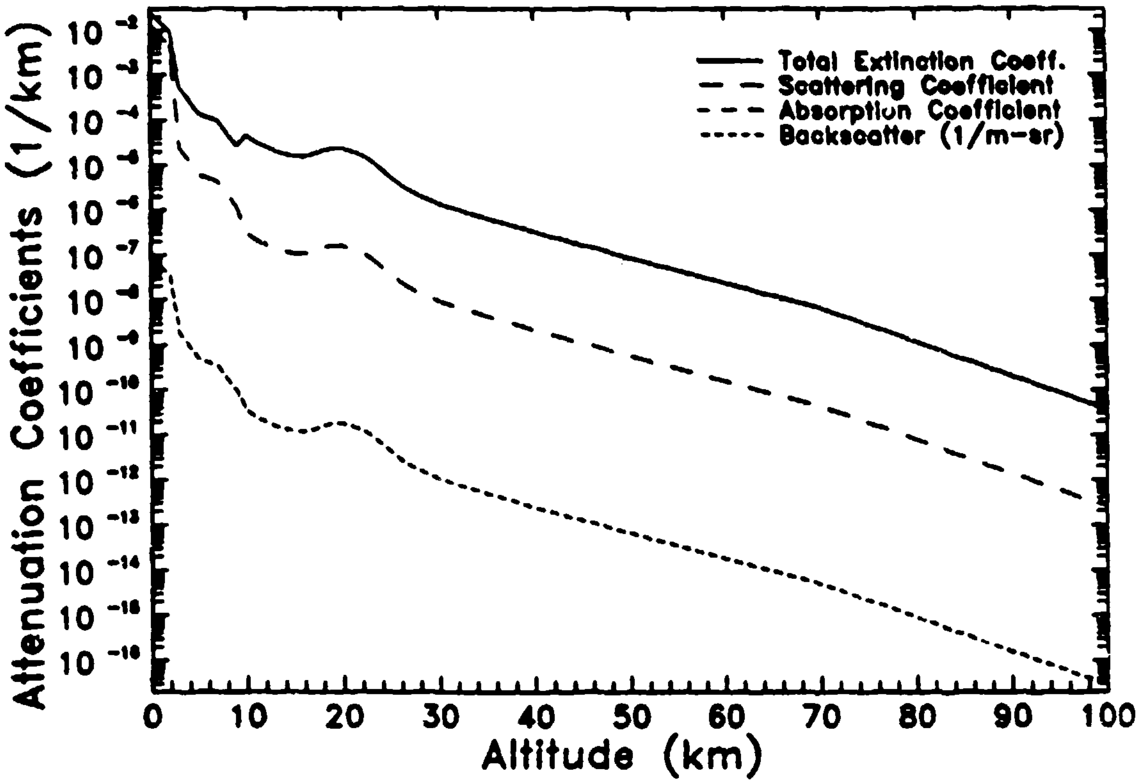

Figure 15. Atmospheric Attenuation and Backscatter Coefficients Versus Altitude

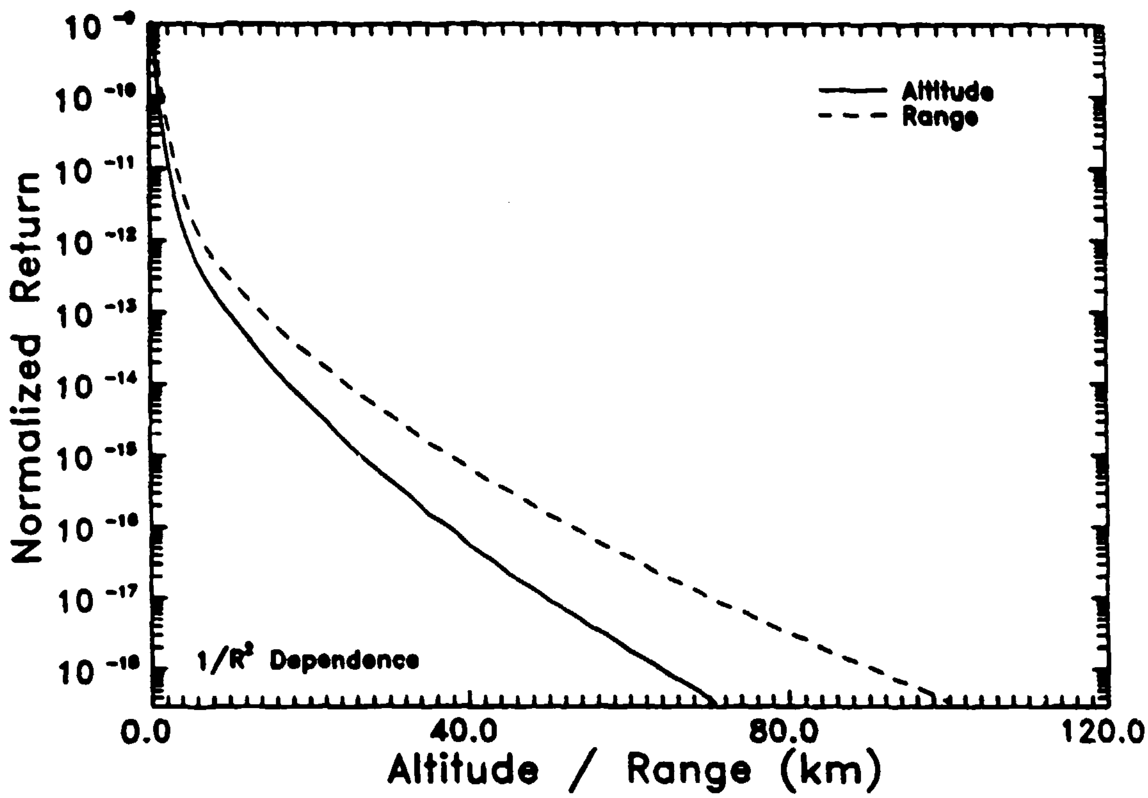

Figure 16. Lidar Backscatter Return with Range Dependence

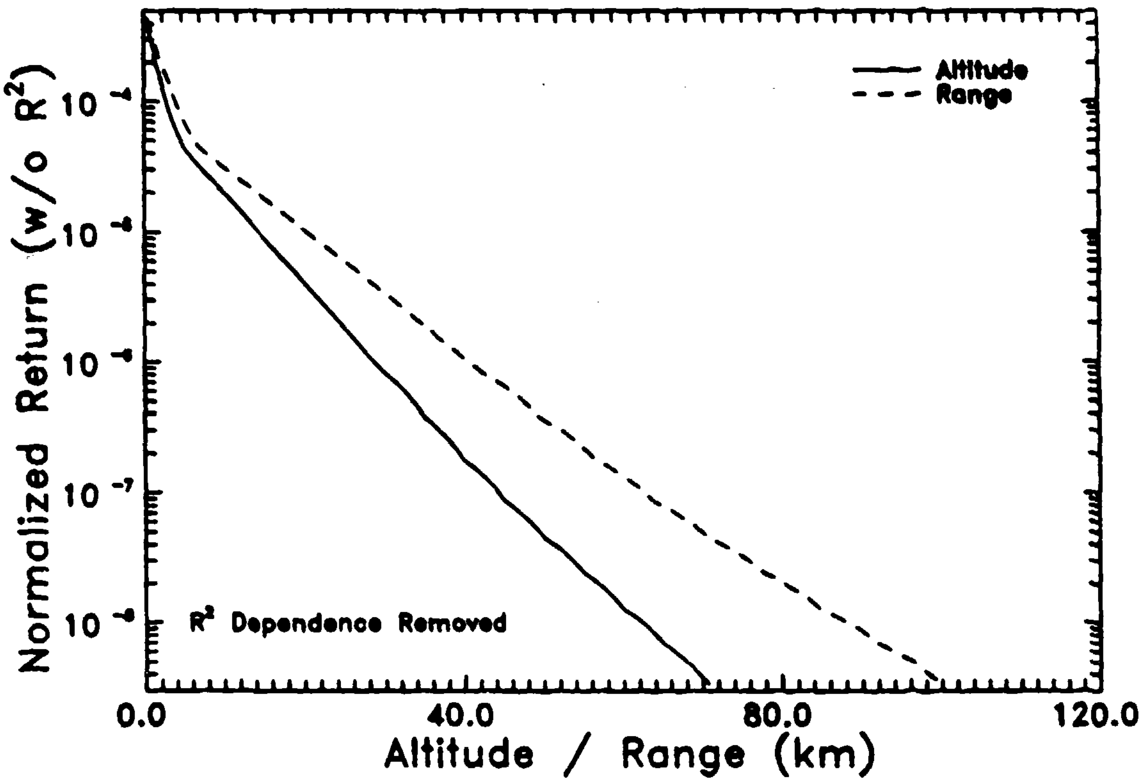

Figure 17. Range Independent Lidar Backscatter Return

6 SUMMARY AND RECOMMENDATIONS FOR FUTURE MODIFICATIONS

BACKSCAT simulates the return form a backscatter lidar system. The atmospheric and lidar system conditions that define the nature of the return are under operator control.

This version of BACKSCAT represents a first attempt to simulate a complete lidar system. A number of improvements to BACKSCAT could be made to make it more representative of an actual, fieldable system.

6.1 Improvement of Model Physics

6.1.1 Multiple Pulses

BACKSCAT simulates the return from a single laser pulse. BACKSCAT could be modified to include multiple pulses. Different pulse averaging techniques could also be included.

6.1.2 Addition of Noise

There are irregularities between lidar pulses that are not accounted for in BACKSCAT. These differences can be accounted for through the addition of simulated noise. Depending on the degree of sophistication desired, one could include one generic noise term or separate terms for laser and receiver electronics noise.

6.1.3 Allowance for Atmospheric Fluctuations

BACKSCAT assumes a static atmosphere. BACKSCAT could be coupled to either a database of time-dependent atmospheric values or to an external program that generates time varying atmospheric profiles.

6.1.4 Consideration of Wind Dependent Aerosols

The aerosol models included in BACKSCAT are also static models. The wind dependent aerosol models such as the desert and Navy maritime models should be added to the list of aerosols that can be considered.

6.1.5 Consideration of Variable Boundary Heights

The boundary heights used to diferentiate one region of aerosols from another are currently fixed in BACKSCAT. One can use other boundary heights but that would entail the use use of a customized set of scaling factors (see section 4.6). It is recommended that the code be modified to allow the use of variable boundary heights. This modification would entail the addition of extrapolation routines that would automatically adjust the scaling factors with the new boundary heights.

6.1.6 Alternate Calculation of Rayleigh Scattering

BACKSCAT currently use a default profile for Rayleigh scattering. The code should be modified to allow the calculation of a Rayleigh scattering profile via the use of radiosonde data or alternate model atmospheres.

6.1.7 Variable Molecular Absorption Profiles

BACKSCAT includes a default molecular absorption profile (see section 4.8) based on a midlatitude atmosphere. BACKSCAT should be modified to allow the use of other molecular absorption profiles, such as those that can be produced by FASCODE. In a further modification, BACKSCAT could be coupled to a special version of FASCODE to calculate the molecular absorption profile for given laser lines.

6.1.8 Allow for Scattering at Other Than 180 Degrees

BACKSCAT is presently set up to model backscattering at 180 degrees. The code should be modified to allow for experimental configurations in which the transmitter and receiver are at different locations. This modification would require the use of a larger data base of phase functions and separate atmospheric path definitions for the transmitter and receiver paths. This modification would also require the addition of field-of-view effects in the processor module.

6.1.9 Addition of Field-of-View Effects

Field-of-view effects are not now currently included. In order to adequately simulate a fielded system, they should be incorporated. As noted in the above recommendation, these effects would have to be included if scattering at other than 180 degrees was included.

6.2 User Features

6.2.1 On-Screen Help Function

BACKSCAT does not include any built-in help capability in which the user can press a key and get information about particular features. The addition of an on-screen help system would aid the user in the use of BACKSCAT. This feature would be intended to augment the user's manual, not replace it.

6.2.2 Alternate Units

BACKSCAT assumes a fixed set of units for the various parameters. The user should be given the option of using other units for parameters, such as the laser power.

6.3 Computer Code Changes

The computer code was written in Fortran 77 which is a highly suitable language for scientific calculations but a restrictive language for developing menu-based, user interface input systems. The C computer language is more suitable for the development of menu-based input systems.

It is recommended that the user-interface system of BACKSCAT be rewritten in C. The portion of the code devoted to the scientific calculations should be kept in Fortran 77. This portion of the code would be connected to the C-based user interface utilizing the mixed-language capabilities of C.

APPENDIX A List of Routines

The following routines comprise the BACKSCAT backscatter lidar simulation program. The listing describes the type of routine and a brief description of what the routine does. All of the routines were written and compiled using Microsoft™ FORTRAN version 4.01 of FORTRAN '77.

Name	Type of Routine	Description
BACKSCAT	(Main Program)	Driver for main menu and simulation menu
ATMPFL	LOGICAL FUNCTION	Generates propagation profile from atmospheric model
ATMSTA	SUBROUTINE	Generates master atmospheric status display
EDATMS	SUBROUTINE	Edits atmospheric structure, driving master atmospheric structure menu and all subordinate menus
EDCNFG	SUBROUTINE	Edits program configuration, driving master configuration menu and all subordinate menus
EDLIDR	SUBROUTINE	Edits lidar system, driving master lidar system menu and all subordinate menus
EXTINT	LOGICAL FUNCTION	Determines extinction coefficients at lidar system wavelength
FBSCAT	LOGICAL FUNCTION	Calculates backscatter normalization factor based on extinction and visibility
GETATM	SUBROUTINE	Loads atmospheric structure from file
GETCFG	SUBROUTINE	Loads configuration from file
GETLDR	SUBROUTINE	Loads lidar system from file
GETMOD	LOGICAL FUNCTION	Reads data from atmospheric model file
GETPFL	SUBROUTINE	Loads propagation profile data
GETRES	SUBROUTINE	Loads molecular resonance absorption data
GETSCL	LOGICAL FUNCTION	Reads vertical profile scaling data
INTEGR	SUBROUTINE	Prompts user for integer input and gets value
INTRPL	SUBROUTINE	Determines interpolation point in index array
JJFILE	CHARACTER *(*) FUNCTION	Converts internal name to file name for specified file type
LDRCLT	SUBROUTINE	Computes lidar attenuation and backscatter
LIDAR	SUBROUTINE	Converts lidar system parameters from menu interface format to simulation format
MESSAG	SUBROUTINE	Displays text on screen message line with specified attributes
NEWNAM	SUBROUTINE	Displays prompt and gets new name
NEWSEQ	SUBROUTINE	Gets new ANSI control character sequence
PHGET	LOGICAL FUNCTION	Locates correct atmospheric model phase function and interpolates on relative humidity and wavelength
PROMPT	SUBROUTINE	Displays text on prompt line with specified attributes
PRSATM	LOGICAL FUNCTION	Parses the atmospheric structure specifications
READUC	SUBROUTINE	Reads input string and converts to upper case
REALNO	SUBROUTINE	Displays prompt for user real number input and gets value
RHINT	SUBROUTINE	Performs appropriate interpolations and computes extinction as a function of relative humidity

Name	Type of Routine	Description
SAVATM	SUBROUTINE	Saves atmospheric structure to file
SAVCFG	SUBROUTINE	Saves configuration to file
SAVLDR	SUBROUTINE	Saves lidar system to file
SAVPFL	SUBROUTINE	Saves propagation profile to file
SCLMOL	SUBROUTINE	Scales molecular backscatter and extinction coefficients by vertical concentration profile
SELECT	SUBROUTINE	Displays menu and gets user selection
STATUS	SUBROUTINE	Displays information in status window
VISINT	SUBROUTINE	Interpolates visibility scaling factor
WAVINT	LOGICAL FUNCTION	Scales propagation parameters for wavelength

Portability was a major criteria in the design of the BACKSCAT program; hence, computer and operating system dependencies have been eliminated where practicable and otherwise isolated in a minimal number of low-level routines. One problem which continues to remain is differences in file naming conventions between different operating systems. The ANSI standard for FORTRAN '77 states that "a file may have a name... The set of allowable names is processor-determined and may be empty."[8]

The problem created by non-standardization of file naming convendons has been resolved in the BACKSCAT code through the use of a function named JJFILE to convert the names of various data sets in the simulation to file names whenever files are read or written. The function subroutine named JJFILE that is supplied with the simulation was written for PC-DOS and MS-DOS operating systems, and will also work satisfactorily under UNIX, but should be reviewed and revised if necessary whenever the simulation is ported to any other operating system.

The function JJFILE accepts two arguments, both of which are of type CHARACTER, and the function itself is also of type CHARACTER. The first argument is the name associated with the data set; under PC-DOS or MS-DOS (and also under OS/2 and UNIX), it may contain a drive and/or path specifier if portability of data files is not an important consideration. The second argument is a file type from Table B-1. The file type is always four characters in length, and the first character is always a period. The version of JJFILE supplied with the program scans the first argument looking for a period indicating that a file extension is already present; if none is found, it concatenates the file type as a file extension. A lidar system named DEMO would be read from or written to a file named DEMO.LDR, while an atmospheric structure named TEST would be read from or written to a file named TEST.ATM.

The file types in Table B-1 were selected based on several criteria. First, they have been chosen to be mnemonic; that is, the file type abbreviation suggests the type of file. Second, they were chosen to conform to the file naming conventions in use on the greatest percentage of computers; this particular set can be used in conjunction with the PC-DOS and MS-DOS, OS/2, UNIX, and VAX/VMS operating systems. Third, they can be abbreviated if necessary for machines that severely restrict the number of characters in a file name; the second and third characters of each designator form a unique pair. These choices, therefore, facilitate the portability and ease of use of the BACKSCAT code.

[8] *American National Standard Programming Language FORTRAN*, ANSI X3.9-1978 (New York, NY: American National Standards Institute, 1978), Page 12-3.

Table B-1. BACKSCAT File Types

File Structure	File Type
Configuration Files	.CFG
Lidar System Files	.LDR
Atmospheric Structure Files	.ATM
Propagation Profile Files	.PFL
Resonant Absorption Profile File	.RES
Internal Aerosol Data Files	.AER
Internal Aerosol Scaling File	.SCL
Simulation Log Files	.LOG
Simulation Output Files	.DAT

APPENDIX C Formats of Data Files Used by BACKSCAT

This appendix describes the internal structure of files used by the BACKSCAT program. The program's interactive interface normally frees the user from concerns about file formats; thus, this information is supplied primarily to facilitate diagnosis of corrupted files.

C.1 Configuration Files

The configuration file contains all configuration information for the simulation. Each configuration includes a default run set, relevant information about the host computer and operating system, and the default status of several program options. Figure C-1 shows the format of the configuration file.

1.	<character>	name of LIDAR system
2.	<character>	name of atmospheric structure
3.	<character>	name of propagation profile
4.	<character>	name of molecular absorption profile
5.	<character>	name of simulation log
6.	<character>	name of simulation output data set
7.	<logical> <logical> <logical>	configuration flags for display
8.	<integer>, <integer>, <integer>	screen length, width, and margin
9.	<integer>, <integer> [,<integer>, ...]	number of, and character sequences for ANSI escape characters
10.	<integer>, <integer> [,<integer>, ...]	number of, and character sequences for ANSI SET GRAPHICS RENDITION character

Figure C-1. Configuration File Format

It is important to note that the data must be input in the specified order and in the correct format; however, the text accompanying the data is optional.

The first six entries constitute the default simulation run set. these names are converted to the appropriate operating system file names by the simulation by a procedure that is dependent upon the operating system.

The four LOGICAL flags in the seventh line control atmosphere display (T for normal display or F for inverted display), propagation mode (T for atmospheric model or F for propagation profile), terminal type (T for ANSI terminal control or F for a generic non-ANSI terminal), and Rayleigh scattering mode (T if Rayleigh scattering is on or F if Rayleigh scattering is off).

The eighth line specifies the screen dimensions and the margins for the status display area. The screen length must be right justified in columns 1--4, the screen width in columns 6--9, and the margins in columns 11--14. Commas should be placed in columns 5 and 10.

The remaining two lines contain the character sequences to be written to the terminal for the ANSI ESCAPE (line 9) and SET GRAPHICS RENDITION (line 10) characters. Each line must have the number of characters in the corresponding string right justified in columns 1--4; the collating positions of the characters are right justified sequentially beginning in columns 6--9 and continuing with columns 11--14, 16--19, 21--24, and 26--29 as required to accommodate a maximum of five characters. Commas should be placed in the intervening columns, and unused fields before column 30 should be blank.

C.2 Lidar System Files

Each lidar system file contains all parameters related to a particular lidar system. The parameters must appear at the beginning of consecutive records of the file in the specified order. Figure C-2 shows the format of the lidar system file.

1.	<real>	Wavelength (μm)
2.	<real>	Transmitted Pulse Energy (J)
3.	<real>	Pulse Duration (μsec)
4.	<real>	Receiver Aperture Diameter (cm)
5.	<real>	Receiver Obscuration Diameter (cm)
6.	<real>	Minimum Range (Km)
7.	<real>	Maximum Range (km)
8.	<real>	Range Resolution (km)
9.	<real>	Sensor Height (km)
10.	<real>	Viewing Azimuth Angle (degrees)
11.	<real>	Viewing Elevation Angle (degrees)

Figure C-2. Lidar System File Format

The comments describing each element, shown in the example, are optional.

C.3 Atmospheric Structure Files

The atmospheric structure file contains the specifications required by the AFGL atmospheric model. Figure C-3 shows the format of atmospheric structure files; data must appear in the exact sequence shown, and all text entries *must* be entered un UPPER CASE TYPE.

1.	<real>	Boundary Layer Height (km)
2.	<real>	Height of Troposphere (km)
3.	<real>	Height of Stratosphere (km)
4.	<real>	Height of Atmosphere (km)
5.	<character>	Boundary Layer Aerosol
6.	<character>	Stratosphere Extinction and Profile
7.	<character>	Upper Atmosphere Aerosol Level
8.	<character>	Aerosol Distribution Profile
9.	<real>	Boundary Layer Humidity (%)
10.	<real>	Troposphere Humidity (%)
11.	<real>	Visibility (km)

Figure C-3. Atmospheric Structure File Format

The first four records in the atmospheric profile input file contain the upper limits of each of the layers. The values in the atmospheric structure file supplied with the BACKSCAT program are correct for the atmospheric data supplied with the program; users changing these values must supply atmospheric data that is correct for the modified values.

The boundary layer aerosol on the fifth record may be URBAN, RURAL, MARITIME, OCEANIC, TROPOSPHERIC, ADVECTIVE FOG, or RADIATIVE FOG.

The stratosphere aerosol extinction and profile are defined on the sixth line. If both the aerosol and profile are "background", this line should contain the key word BACKGROUND. For volcanic profiles, columns 1--5 contain the extinction (FRESH, AGED, or BKGD., right justified, columns 6--10 contain the profile (MOD., (moderate) HIGH, EXT., (extreme) or BKGD., also right justified, column 11 must be blank, and columns 12--15 must contain the key word VOLC (volcanic).

The upper atmosphere aerosol on line seven may be either NORMAL or EXTREME.

The eighth record of the file contains the aerosol distribution profile, which may be either SPRING/SUMMER or FALL/WINTER.

The boundary layer and troposphere (relative) humidity are given in percent on the ninth and tenth records respectively; thus, a value of 70.0 corresponds to 70% relative humidity.

The last record contains the visibility in kilometers if it is positive, or a uniform extinction coefficient if it is negative.

C.4 Propagation Profile Files

The propagation profile file may be either read or written by the simulation, depending upon the simulation mode. In either case, it is a table whose columns are: (1) altitude, (2) aerosol extinction coefficient, (3) aerosol absorption coefficient, (4) aerosol scatter coefficient, (5) aerosol backscatter coefficient, (6) molecular extinction coefficient, and (7) molecular backscatter coefficient. The table must be arranged such that each record after the first is at a greater altitude than the previous record. A maximum of 100 records are permitted.

C.5 Molecular Absorption File

The user may supply a two-column file to specify absorption by molecular resonances as a function of altitude. The first column of this file must contain the altitude in kilometers and the second column must contain the absorption coefficient in inverse kilometers. The data must be arranged such that the altitudes are in increasing order; that is, the altitude on each record must be greater than the altitude on the previous record.

C.6 Simulation Log Files

The simulation generates a log file when it is executed. This log file, written in standard text format, allows the execution of the simulation to be traced. The actual syntax of the simulation log is dependent upon the simulation configuration options; thus, the information written to the log is documented in the log itself.

C.7 Simulation Output File

The simulation output is a standard data file, in text format, containing a table of the lidar propagation and backscatter information as a function of range. The columns of the table are: (1) range, (2) altitude, (3) cumulative attenuation, (4) lidar backscatter, (5) normalized backscatter, (6) range-compensated backscatter, and (7) normalized range-compensated backscatter. This data may be plotted using most commercially available plotting programs.

REFERENCES

1. Klett, J. D. (1981) Stable Analytical Inversion Solution for Processing Lidar Returns, Applied Optics 20:211.
2. R.W. Fenn et al. (1985), "Optical Infrared Properties of the Atmosphere", Chapter 18 in *Handbook of Geophysics and the Space Environment*, A.S. Jursa (ed.), Air Force Geophysics Laboratory, Hanscom Air Force Base, Massachusetts, AFGL-TR-85-0315, ADA167000, and E.P. Shettle (1988) Private Communication.
3. *American National Standard Programming Language FORTRAN*, ANSI X3.9-1978 (New York, NY: American National Standards Institute, 1978), Page 12-3.